CHAPTER 25

HIGH ALTITUDE ELECTRO-MAGNETIC PULSE (HEMP) PROTECTION SYSTEMS

25-1. General HEMP protection systems

Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) facilities contain miniature solid-state electronics. These devices will fail when subjected to voltages that exceed the dielectric strength of the component or when the device melts as a result of heating from currents induced by a radio frequency (RF) pulse. Most people are familiar with the effects of lightning upon solid-state equipment. Other sources are High Power Microwave (HPM), Ultra Wide Band (UWB) waveforms, and High-Altitude Electromagnetic (EM) Pulse (HEMP). A nuclear weapon detonated 300 km above the United States can blanket the entire continental United States with the HEMP effects.

a. Reliance on electronic technology. Military facilities are becoming increasingly reliant on automated systems that take advantage of modern electrical and electronic technology. Facilities are equipped with state-of-the-art computerized systems for expeditious, reliable, and cost-effective operations. However, the EM properties of many electronic components can make entire systems susceptible to upset or permanent damage due to the environmental effects of HEMP. Systems are also susceptible to the compromise of security information by the unintentional intelligence-bearing emanations of EM signals. Thus, with the benefits of automation has come an increased vulnerability.

b. Early planning. Techniques to protect a facility are usually selected during the early design phase. If it is anticipated that a facility may someday acquire equipment that must be protected, early planning can avoid costly retrofitting later. The decision to harden will be based on the interaction of mission criticality, EM environment, security requirements, and costs.

c. Far-reaching effects. HEMP is dangerous because this event has far-reaching effects at distances where other nuclear environments are either nonexistent or inconsequential and because of its high level of broad spectral energy. However, the spectrum included under HEMP does not cover all EM environments. For example, the characteristic pulse rise time and possible conducted current waveforms for lightning differ from those for HEMP; thus, hardening against HEMP does not necessarily protect against lightning.

25-2. HEMP procedures

HEMP is defined as EM pulses produced by nuclear explosions at high altitudes. HEMP hardened facilities are intended to provide vital communications at a time when unhardened facilities are likely to fail. If initial HEMP hardness for a facility degrades during day-to-day operations, then unexpected system failures could seriously compromise communication assets as a result of a nuclear event. Because degradation in HEMP hardness has little effect on the normal facility operations, specific surveillance, maintenance, and operational procedures must be employed to detect and repair degradation in facility hardness.

25-3. Modes of HEMP entry

Modes of HEMP entry include diffusion, leakage through apertures, antennas, and conductive penetrations.

a. Diffusion through the shield. HEMP fields diffuse through imperfectly conducting walls of shielded enclosures. The diffusion is greatest for magnetic fields and is a low-pass filtering event, as shown by the magnetic shielding effectiveness curve. Thus, the field that reaches the inner region of a shielded enclosure is basically a low-frequency magnetic field. This effect is greatest in an enclosure with solid metal walls. It is also seen somewhat in enclosures with metal rebar or wire mesh reinforcement. The reduced shielding effectiveness at high frequencies for rebar and wire mesh structures allows a significant fraction of the incident HEMP environment to penetrate to electronics inside the enclosure.

b. Leakage through apertures. Openings and other shielding compromises include doors, windows, holes for adjustments and display units, seams, improperly terminated cable shields, and poorly grounded cables. Unless properly treated, each opening is a leak through which the HEMP field can couple directly into the shielded enclosure. Leakage through an aperture depends on its size, the type of structure housing it, and its location. The aperture responds to both total magnetic and electric fields at the site of the leak.

c. Intentional and inadvertent antennas. Intentional antennas are designed to collect EM energy over specified frequency bands. However, there will also be an out-of-band response to HEMP. Because the incident HEMP field has a broad frequency spectrum and high field strength, the antenna response must be considered both in and out of band. Analytical models are available for determining the different antennas' responses to HEMP. These models, along with the incident field, yield the HEMP energy that appears at the connecting cable. This energy later reaches the electronic systems inside the enclosure at the other end of the connecting cable. Inadvertent antennas are electrically conducting, penetrating external structures, cables, and pipes that collect HEMP energy and allow its entry into the enclosure. As a rule, the larger the inadvertent antenna, the more efficient energy collector it is in producing large, transient levels in the enclosure. The coupling for inadvertent antennas can be analyzed using transmission line and simple antenna models.

d. Conductive penetrations. Many factors affect the coupling of EM energy to penetrating conductors. The HEMP waveform characteristics, such as magnitude, rate of rise, duration, and frequency, are each important. Further, the observer's position with respect to the burst is a factor. Because the interaction between fields and conductors is a vector process, the direction of arrival and polarization is also important. Conductor characteristics also affect HEMP coupling. These include conductor geometry (length, path, terminations, distance above or below the earth's surface), physical and electrical properties that determine series impedance per unit length (including diameter, resistivity, and configuration), and the presence and effectiveness of shielding. For overhead or buried conductors, the electrical properties of soil affect coupling. Many elements of a facility can act as efficient collectors and provide propagation paths for HEMP energy. HEMP can couple to structures such as power and telephone lines, antenna towers, buried conduits, and the facility grounding system. Actual antennas, nonelectrical penetrators such as water pipes, and any other conductive penetration can couple HEMP energy into a structure. In addition, if the structure is not shielded or is not shielded well enough, HEMP can couple to the cables between equipment inside.

25-4. Equipment susceptibility

System damage or upset from HEMP is caused by currents and voltages induced in conductors exposed to a free-field or partly attenuated EM pulse coupled to circuits. The narrow resonance results from circuits of high Q (quality factor) which have low resistive dissipation of energy. External conductors, structures, and internal conductors act as unintentional receiving antennas and “coupling” paths. They can deliver the resulting HEMP-induced currents and voltages to sensitive components of electronic equipment. The HEMP-induced currents on exterior long-line penetrators, such as power and telephone lines, can have amplitudes as high as thousands of amperes. Currents induced on internal cable runs can be as high as hundreds of amperes for most structures and even higher in facilities with lower systems engineering (SE). It is important to note that exterior voltage transients can be in the megavolt range, and it would be normal to expect an order of thousands of volts from internal coupling.

a. Effects of transients. Transients of these magnitudes can be delivered to electronic circuits, such as integrated semiconductor circuits, which can be damaged by only a few tens of volts, a few amperes, or less. These circuits also operate at relatively low levels (e.g., five volts and tens of milliamperes) and can be upset by HEMP currents of similar values. If the large exterior coupled transients were allowed to enter a structure that had no HEMP protection treatment, even relatively “hard” devices, such as relay coils, could suffer damage.

b. Equipment responses. HEMP produces two distinct responses by equipment and system components: upset and damage. Upset is a non-permanent change in system operation that is self-correcting or reversible by automatic or manual means. Damage is an unacceptable permanent change in one or more system parts.

c. Damage thresholds. The passive elements most susceptible to damage from HEMP-induced currents are those with very low voltage or power ratings and precision components for which a small change is significant. Resistor failures due to high-level pulsed currents are caused by energy-induced thermal overstress and voltage breakdown. Resistor failure threshold can be calculated from the resistor’s parameters and the empirical relation. Exposure of capacitors to transient currents sets up a voltage across the capacitor that increases with time. For non-electrolytic capacitors, this voltage keeps rising until the capacitor’s dielectric breakdown level is reached. That point is typically ten times the direct current (DC) voltage rating. For electrolytic capacitors, the voltage relationship holds until the zener level of the dielectric is reached. After that, damage can occur. The damage threshold for electrolytic capacitors in the positive direction is three to ten times their DC voltage rating. For the negative direction it is one-half their positive failure voltage. Transformer and coil damage due to HEMP-induced currents results from electric breakdown of the insulation. The pulse breakdown voltage is typically 5500 volts for power supply transformers and 2750 volts for small signal transformers.

25-5. HEMP protection systems

Traditional methods of electromagnetic interference (EMI) isolation often use metal enclosures to prevent unwanted radiation from entering the circuit. These shields provide effective protection along with good grounding techniques, therefore, HEMP protection systems are static as they do not have any moving parts. An exception to this is finger stock material that springs into place when doors or windows are closed. Only during an electromagnetic pulse (EMP) environment does the system function to shield the hardened facility. HEMP protection system components should not be disturbed or disconnected.

a. Electronic surge arresters. An area in which care must be taken to ensure compatibility in EM integration is surge protection. Some surge arresters used for lightning do not clamp fast enough to protect against HEMP. Some used for HEMP may not have great enough current carrying capacity for lightning protection in all situations.

b. Shielding. For HEMP-hardened facilities, some kind of EM shielding is essential. Shielding involves the use of a barrier or series of barriers to reduce the magnitude of the EM energy incident upon the electronic or electrical system to be protected. Shielding philosophy can be developed around different approaches.

(1) Global shielding (or hardening) is a protection concept that uses an overall shield to encompass the entire facility. In this approach, all conducting penetrations and all apertures are protected at the shield. The intent is to keep all HEMP fields and HEMP-induced transients outside the protected volume. The global shield could be placed on the entire outer walls, ceiling, and floor (surface) of the facility, or it could be reduced to a smaller volume that contains all sensitive equipment to be protected. The most common shield material for global shielding of ground-based facilities is sheet steel with welded seams, although other designs can provide adequate global HEMP shielding.

(2) Tailored shielding is a protection concept in which shielding is designed and constructed according to specific protection requirements for the equipment involved. After defining the system to be protected, its possible operating configurations, the expected HEMP environment, coupling paths, equipment sensitivities, and subsystem/system criticalities, the required protection levels for various subsystems or groups of subsystems can be defined. Tradeoff studies may be performed for comparing various shielding arrangements to verify that they meet safety margins in protection, cost-effectiveness, maintainability, survivability, flexibility, and other requirements. The objective is to optimize protection for the specific mission-critical system. Tailored shielding options may include global shielding, zonal shielding, shielding of cabinets or components, or combinations thereof. In a typical tailored protection design, discrete protection will be provided to eliminate specific, localized deficiencies.

(3) Zonal or topological shielding is a concept in which a facility is divided into zones, with shielding barriers located topologically in a shield within a shield configuration. The outer zone is designated zone zero; zone one is inside shield one but outside shield two. Zones and shields are assigned increasingly larger numbers as they progress toward the more deeply nested areas.

(4) The term "system configuration" identifies which way the cables, wires, equipment, and subsystems are laid out in relationship to each other, as well as the relationship of these items to the topological boundaries. In some instances, the cables, connectors, and equipment casings are actually part of the topological protection. System configuration as defined does not directly attenuate the environment, but it is an important element in the topological protection concept. The system configuration influences protection design requirements since some configurations are easier to protect than others (e.g., co-location of all mission-critical equipment). Thus, the system configuration should be coordinated with the protection design and the protection topology will be optimal for a specific configuration. During the facility life cycle, the protection design may be required to accommodate some changes in configuration. To ensure that the configuration's design modifications do not compromise or defeat the protection, careful configuration management is necessary. The topology should be designed to tolerate configuration changes that are totally within a boundary. The boundary can never be violated (for example, opened)--only extended. All modifications must be subjected to review by HEMP experts to ensure continual compliance with the HEMP hardening requirements.

(5) Conductive or metallic cable shielding or conduit is used in the zonal/topological protection concept to extend the boundary formed by equipment enclosures and thus provide a way to interconnect elements while maintaining boundary continuity. Cable shielding is also used to protect a wire or wires as they travel from one boundary to another. This would be the case with a shielded RF signal traveling from its entrance into a building to the RF receiver. From a HEMP standpoint, the shielding attenuates coupling of radiated energy within the first boundary as the signal travels to the receiver. Of course the shield is somewhat reciprocal in that it also prevents signals from radiating out of the cable. The main feature of cable shielding is continuity of the boundary provided by the cable shield/connector combination that may require special joints.

(a) Another way to maintain this continuity and provide cable shielding is by using steel conduit to house all wires and cables. The steel conduit will provide substantially higher shielding levels than the cable shields.

(b) Both cable shields and conduit connected to a shielded zone must have equal or greater shielding effectiveness than the shield.

c. Grounding. The grounding system for a HEMP protected facility shall use an equipotential ground and is connected to a welded stud that does not penetrate the shield. Another stud welded to the opposite side of the shield then will be connected to the exterior grounding system.

d. Shield penetration protection. All shielded zones will require penetrations to allow entry of equipment, personnel, electric power, communications, control signals, ventilation, water, fuel, and various fluids. Without protection, these penetrations compromise the shield.

(1) Large access doors are often necessary to provide an entry for equipment, supplies, or vehicles into HEMP hardened facilities. In facilities that require blast overpressure protection, large blast doors are used. These doors generally use one or more thick steel plates to provide protection. The door's inherent shielding ability is thus high, but its large size presents a difficult gasketing problem. If blast protection is not required, it is still necessary to design the door with a high degree of structural strength. This step is to ensure that the door can provide the necessary gasket compression force and that proper mechanical alignment of closure contact surfaces is maintained.

(2) Two concepts are commonly used for personnel entrances: conventional HEMP/radio frequency interference (RFI) shielded doors and personnel tunnels that act as waveguides below cutoff. The shielded doors generally use metal fingerstock or EMI/RFI gaskets to provide an EM seal around the door jamb periphery. Currently available gasket and fingerstock doors require regularly scheduled maintenance and/or replacement to maintain required shielding levels. The gaskets are relatively easily damaged and also require replacement. Air-expandable doors may also be used, although they typically have more maintenance problems. These doors generally use a movable subassembly of two shielding plates on a framework that is moved on rollers in and out of a steel-framed opening. When closed, air expansion tubes cause the two shielding plates to make uniform surface contact with the frame inner surfaces.

e. Electrical penetrations. A common feature for electrical penetrations in a global protection approach is a cable entry vault to prevent large currents on external conductors from being conducted into the facility. Ideally, all penetrations should enter a single vault. In some cases, however, it may be necessary to separate the vault into two compartments or to use two vaults for penetrations by different types of lines: power, signal and control, and antenna. The vault must be connected directly to the external facility ground system. Conductive penetrations, such as a conduit, waveguide, or shielded cable, must have a circumferential weld or other means of providing good electrical connection at the intersection with the entry vault. The cable entry vault serves three purposes:

(1) To insure that penetrating conductors do not cause conducted HEMP energy to enter the protected topology.

(2) To contain and divert penetrator-conducted HEMP energy to the boundary exterior.

(3) To contain or divert radiant EM energy resulting from the activation of transient suppression devices subjected to a conducted pulse.

f. Transient suppression devices and filters. Transient suppression devices fill a critical gap in the concept of topological protection. The necessity of supplying power to a facility and of communicating over cables or antennas are two major factors contributing to their use. Power lines entering a facility are typically connected to an unshielded power grid so that large, conducted currents must be bled off to prevent their entry into a facility. These currents are diverted to the exterior boundary of the topology. This boundary can be an overall external shield or an enclosed entrance vault. Antennas, such as for high-frequency (HF) communications, are designed to gather EM signals (at wavelengths in the HEMP frequency spectrum) and to apply these signals to the center conductor of a shielded cable. The HEMP transients associated with an HF antenna can be, by far, the largest single signal entering a facility. Transient suppressors often are used in conjunction with filters. Filters are frequency-selective whereas surge suppressors are amplitude-selective. Filters often are used to attenuate transients associated with the non-linear operation of surge arresters. They also are used for selectively passing (or stopping) frequency bands as in the case of antenna cable penetrations. Transient suppressors are an integral part of the EM topology, demanding specific installation techniques as will be seen later. A spark gap is a surge suppressor that provides a conducting path to ground when the voltage across the device exceeds the gap breakdown level. Spark gaps with a high current capacity do not operate quickly enough to block all HEMP energy transients entering the vault. For this reason, it may be necessary to use other protection devices in conjunction with the spark gap.

g. Electromagnetic isolation. The EM isolation concept involves the use of elements either immune to interaction with EM radiation or which provide a current path interruption. Optical fibers are examples of elements immune to EM radiation that can be used to reduce the number of conductive penetrations. For practical purposes, optical fibers can be used for long communications links without signal interference from HEMP. Further, they can be used to enter shielded zones through waveguide below cutoff penetrations without compromising the EM shielding effectiveness.

h. Dielectric isolation. Other isolation techniques include using dielectric isolators for shield penetration when external metallic EM energy collectors are involved. Examples are control rods or cables (normally metallic), piping systems for fluids, and metallic duct systems for air. Dielectric sections are installed at or near the shield to prevent the energy induced on the external metallic part from being conducted through the shield. Dielectric control rods can enter through a shield in the same way as optical fibers, that is, through a waveguide-below-cutoff section.

i. Isolation switching. Although not recommended now, isolation switching has been provided at facilities so they can use commercial electric power during routine operation, but can switch to internal generators or power systems in the event of an emergency such as nuclear attack. Since the commercial power wiring is a source of significant HEMP energy injection through a shield, switching to internally generated power is an obvious advantage when advance warning of impending nuclear attack is received and throughout the entire nuclear attack cycle. This concept applies to communications lines and control lines as well as power lines. Switching used in past facility designs has been called “alert attack” switching. Such switching must provide adequate switch contact separation to prevent arcing, and must be designed to reduce coupling interactions between wiring and switch contacts to acceptable levels.